Dynamic Adaptive Topology Control in Highly Mobile Environment

Diya Ann Kuruvila, Jennifer S Raj

Abstract - One of the important factors that affect the connectivity of a network is transmission power. As the node moves connectivity gets affected. Hence network lifetime and capacity gets affected. Network partioning can occur if a loss in connectivity occurs. Planar structures helps to overcome the connectivity problems to certain extend but they do not take into account network dynamics. Hence in order to improve the network performance an adaptive dynamic topology control is presented in which network is divided into various zones and in accordance with the network dynamics, the nodes adjust their topology independently. Network performance is ensured with best quality of service by selecting the links based on the transmission power of nodes. Performance of the algorithm is witnessed by setting the node mobility at different speeds. Simulation results shows that the proposed work out performs existing work in terms of 1)improved connectivity 2)less packet drop 3) greater throughput .

Index Terms - Dynamic Adaptive Topology Control (DATC), Gabriel Graph (GG), Relative Neighborhood Graph (RNG), Local Minimum Spanning Tree (LMST), Topology Control, Topology Construction, Topology maintenance

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1. INTRODUCTION

The main aim of topology control is to reduce the number of active nodes and active links in a network for further use in a network. Topology control aims in efficient use of scarce energy resources for increasing the capacity and life time of a network. Features of topology control include (i) it must be fully distributed, asynchronous and localized (ii) topology generated must preserve connectivity and relies on bi directional links only (iii) must generate a topology with small node degree. Topology control includes topology construction and topology maintenance. Topology construction helps in constructing the reduced topology and topology maintenance is in charge of maintaining the reduced topology so that characteristics like connectivity and coverage is preserved. One way of constructing the topology is by changing the transmission range of nodes. Transmission ranges are set in such a way that connectivity is preserved and energy is saved. It stands for common power. COMPOW [1] is a routing based approach. Here the nodes closed to each other will be transmitting at a lower power such that it will not affect traffic carrying capacity of other nodes.

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Transmission ranges are set in such a way that connectivity is preserved and energy is saved. It stands for common power. COMPOW [1] is a routing based approach. Here the nodes closed to each other will be transmitting at a lower power such that it will not affect traffic carrying capacity of other nodes. It is needed as power control affects the traffic carrying capacity of a network. But here considerable message overhead is there and requires knowledge of routing table. Cone based topology control (CBTC)[2] is a direction based transmission range approach where the nodes should have directional information
Here we should not transmit at higher power as power increases with distance. Also message exchange needs to be there for finding directional information. XTC[3] is a neighbor based transmission range approach where every node sends its orders its neighbors based on some criterion for e.g., link quality . This will be sent at maximum power. Based on its own order, and the orders of its neighbors, the node determines the set of “logical” links. It does not require directional information and works without GPS. But here the problem is that there is no limit on the number of physical neighbors and there is no guarentee for connectivity. Local minimum spanning tree (LMST) [4] was designed as some of the algorithms like CBTC, are based on some message exchanges and some require explicit propagation channel modes. In LMST every node collects information about one hop neighbor and forms a set called N1[u]. MST is then calculated using Kruskal algorithm or Prims algorithm. It uses a tree based approach.

In this paper dynamic adaptive topology control is presented where the nodes adjust their topology independently inaccordance with the network dynamics. The contributions of the paper include: (i) preserves network connectivity thereby maintaining the lifetime of the network (ii) small node degree reduces MAC contention and interference (iii) better packet deleivery ratio than previous works by reducing the number of loops.

The rest of the paper is organized as follows: In section 2 related works is presented.In section 3 preliminaries is described. In section 4 proposed work is presented. In section 5 performance analysis and simulation results are shown. Section 6 concludes the paper.

2. RELATED WORK

The paper is being influenced by lot of research efforts. There has been great deal of work in the area of topology control of which some has been summarized below.

Common Power [1] is a routing based approach. Power control affects the traffic carrying capacity of the network. If power control is not there interference will be worse and also if the source is closer to destination transmitting at higher power leads to wastage. For choosing transmit power bi- directionality of the link is critical. Nodes should find a way to ensure bi directionality without breaking existing protocols. This leads to COMPOW. If the nodes are closer to each other it is better to transmit at low power. Here we assume that all the nodes operate at common power thereby increasing network lifetime, traffic carrying capacity. The need for bi directional links is that we cannot guarantee that by single hop packet will reach destination. Hence acknowledgements should be there. Thus bi directional links should be there.

Cone Based Topology Control [2] is a direction based topology control algorithm. The main aim is that node 'u' transmits with minimum power Pu,α which is required to ensure that in every cone of degree α around 'u' there is some node which 'u' can reach with Pu,α.. Network connectivity preserved by taking α=5π/6. CBTC requires only directional information that is it must be possible to estimate the direction from which another node is transmitting. Directional information is found out by using directional antenna. The network is divided into small cones with angle α. In each cone there should be a neighbor node. The algorithm takes a parameter α and each node tries to find at least one neighbor in every cone of degree α centered on 'u'. Node 'u' starts the algorithm by running HELLO message using low transmission power and collecting replies it gradually increases transmission power to discover more and more neighbors and keeps a list of nodes that it has discovered and also the direction in which they are located. It then checks whether each cone of degree α contains a node. The check performed by arranging nodes according to their angles based on some reference node. The algorithm terminates when there is no gap α or the maximum power has reached. Here also we can't transmit at higher power as power increases with the nth power of distance. Also message exchange needs to be there for finding directional information.

Rogen Wattenhofer et al. [3] presented XTC which is a neighbor based approach. It is a simple and local algorithm and does not require the node position. It can work without GPS. Nodes order their neighbor as per the link quality (Euclidean distance from node) There is no upper bound on the number of neighbor. The basic idea is that at the beginning every node orders its neighbors (set of nodes in the maximum transmitting range) according to some criterion (e.g., link quality) then, every node transmits its order at maximum power, based on its own order, and on the orders of its neighbors, every node determines the set of "logical" links. The algorithm involves 3 main steps a) neighbor ordering) Neighbor order exchange c) Edge selection. First the node 'u' broadcasts its order to its neighbors. The neighbors also broadcast there order to 'u'. Node 'u' arranges orders in the decreasing order in terms of link quality. If a node order appears earlier in the order than another node first one will be processed first.

Li, .Hou et al.[4] presented local minimum spanning tree (LMST) which is a spanning tree based approach. In topology control networks nodes determine their transmission power and define network topology by forming neighbor relation. In MST nodes will be collecting information about neighbors. Degree of node is bounded by 6. Unidirectional links are removed so that resulting topology contains bidirectional links. If the node degree is small, it reduces contention and interference. Average node degree is small. The MST of a graph defines the smallest subset of the edges that keeps the graph in connected. MST is a sub graph of RNG. There are two main algorithms- Kruskal algorithm and Prims algorithm. Kruskal algorithm chooses edges of a graph that has minimum weight. The edges (E) are arranged in an increasing order. In Prims algorithm MST is built by putting an arbitrary node in the tree. This eliminates the search step required in Kruskal algorithm. The edges are added to the graph if they are smaller than the previous edges already in the graph.

Li, Wan et al.[5] presented a power efficient sparse spanner for wireless ad-hoc networks. Scalability is important due to limited number of resources. One approach is to maintain linear number of links. This is called sparseness. Power stretch factor is a measure of efficiency. Power stretch factor is defined as the ratio of minimum power needed to support any link to the least necessary. Power stretch factor for Gabriel graph is 1, for Yao graph it is bounded and for relative neighborhood graph it can as long as network size-1. No geometric structure with the constant degree bound has the least energy consumption path for all nodes. To generate a bounded degree graph with constant length stretch factor replace directed star consisting of all nodes towards a node 'u' by a directed T(u) of a bounded degree with 'u' as sink

K-neigh[6] is also a neighbour based approach. Nodes do not know their positions ,they just calculate the distance between itself and its neighbours.This assumes continuous communication range and defines it untill it reaches k neighbours. Connectivity is not guaranteed. We estimate the value of k that guarantees connectivity of the communication graph with high probability,preferred value of this 9. It is a fully distributed, asynchronous, and localized protocol that follows the above approach and uses distance estimation

Alexis Papadimitriou et al.[7] presented a survey on topology control algorithm in wireless sensor networks .In wireless ad-hoc networks there is a possibility of deploying so many nodes in relatively small area. The nodes interfere with each other and sometimes use large transmission power to reach remote nodes. These problems can be solved by topology control techniques where a deliberate attempt is made to reduce the initial topology of the network. Gabriel graph is one hop realizable, planar, connected and localized algorithm. Power stretch factor is bounded by one but the maximum node degree is unbounded. Relative neighbourhood graph is also one hop realizable, planar, and connected and direction based approach. Here power stretch factor is unbounded.

Karp et al.[8] presented Greedy Perimeter Stateless Routing. It is based on planar graph traversal. Planar graphs are graph with no intersecting edges .It is performed on per packet basis and does not require nodes to store additional information. The packet forwarding technology used is greedy packet forwarding. Sender forwards the packet to an intermediate node which then forwards the packet position information regarding location of destination is included in the packet header. Greedy packet forwarding includes 1) most forward within transmission range 2) Nearest with forward progress (NFP). In most forward within transmission range sender sends the packet to a node which is at the end of the transmission range.

In nearest with forward progress [NFP] packet is transferred to nearest neighbour. But the main drawback is that it may fail to find a path between sender and destination even if a route exists. To counter this problem packet should be forwarded to the node with least backward progress. But here there is a possibility for looping. It enters into greedy mode when it reaches a node closer to its destination and enters into recovery mode when it arrives at local maximum.

3. PRELIMINARIES

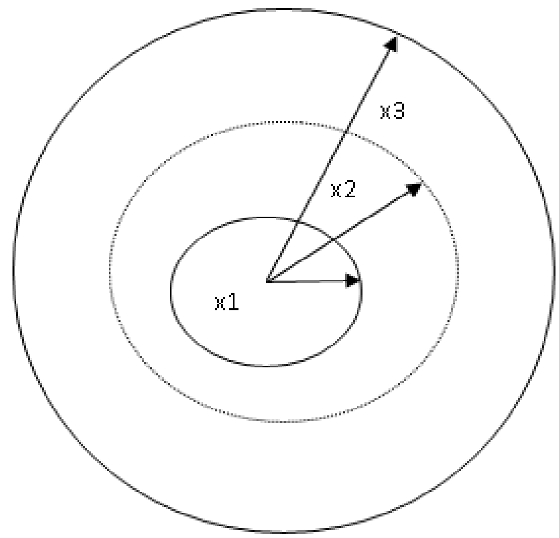

Figure:1 Transmission power needed to locate nodes

Network connectivity is affected by the transmission range of the nodes. Transmitting at high power will affect the transmission range of other nodes if the source node is closer to destination node. By adjusting the transmission power during transmission a node can reach the next node. But frequently adjusting the transmission power will not be suitable for nodes in most of the networks. Network may get congested if the transmission range is high. But the transmission range cannot be too small. If it is too small traffic can increase in the given area.

The above figure shows the transmission power needed to locate the nodes. Here x3>x2>x1. Whenever a node wants to communicate to other nodes, it uses transmission power to locate other nodes. For this it uses transmission power. The nodes gradually increase the transmission power to locate more and more nodes. If the node located at the innermost circle wants to locate its neighbors, it has to adjust its transmission power. By using x1 the node will not be able to locate those neighbor nodes that are outside the coverage region. Hence it gradually increases the transmission power from x1 to x2 . The node then stores this information and tries to access other nodes that need to be communicated. Hence the power is increased from x2 to x3. This proceeds till the node is able to discover those nodes that need to be communicated. Network dynamics were not taken into account in the previous works and hence they suffered from certain drawbacks. (i) Traffic load and channel status were not considered. Hence the nodes suffered from large amount of retransmissions when the channel status was deteriorated. As a result throughput and energy efficiency were also affected. (ii) Energy of the nodes was not considered. In order to improve network lifetime nodes should not lose their energy un necessarily.

Thus the need for adaptive topology control comes in to the picture wherein the nodes are able to adjust their topology independently in accordance with the changing network dynamics but at the same time maintaining the connectivity and lifetime of the network.

4. PROPOSED WORK

In dynamic adaptive topology control (DATC) network is divided into zones. Communication between different zones takes place through a central node which acts as a head node. When the energy of the head node drops re-election of head node takes place and the node having higher energy becomes the new 'head node'. Dynamic adaptive topology control is based on three well known planar structures which are described as follows.

4.1. Relative Neighbourhood Graph [22] denoted by RNG is a direction based protocol and has an edge u,v if and only if||uv||<= 1 and the intersection of two open disks centred at u, v with radius ||uv|| contains no other node. RNG is the subset of GG and is planar and one hop realizable. It uses a cone based approach. Here also the node 'u' grows its transmission power until it finds a neighbour 'j' which is then added to its neighbour list. It is more sparser when compared to GG. The power stretch factor is unbounded .It is a distrributed protocol which preserves connectivity. The degree of the node is n-1.

4.2. Gabriel Graph [15] Gabriel Graph denoted by GG has an edge uv if and only if ||uv||<=1 and the open disk using ||uv|| as diameter contains no other node. It is a planar and localzed algorithm and is also one hop realizable, symmetric and connected. Power stretch factor which is a measure of efficiency is unity in Gabriel graph. Also the power consumption is given by |uv|2. The power stretch facto bounded by one but the maximum node degree is unbounded(<=n-1).

4.3 Local Minimum Spanning Tree [3] denoted as LMST builds a connected global MST like topology with only bidirectional links. Each node constructs the topology independently with the information that is locally collected and keeps one–hop on-tree nodes as neighbors. Topology constructed preserves the network connectivity but requires location information and the resultant topology gets converted into a one with only bi-directional links (after the removal of unidirectional links). The bi directionality of links is essential when the packets are to be transferred in an unreliable wireless medium. It is also important in link level acknowledgements and also for medium access control mechanisms like RTS/CTS in IEEE 802.11. The degree of the node is bounded by 6. Small node degree reduces contention and interference. LMST delivers most of the data.

Let G=(V,E) be an undirected simple graph. The set of nodes that node 'k' can reach by using the maximum transmission power can be given as $NV_k(G)=\{l \ \varepsilon \ V(G) : d(k,l) <= d_{max}\}$ LMST involves 3 phases (i) information exchange: Each node 'k' collects information regarding other nodes in the network. This is done usually by broadcasting 'HELLO' message at maximal transmission power. Information in the hello message includes node id and node position. The interval between the broadcast of HELLO messages depends on the mobility of nodes..Node 'k' gradually increases its transmission power to reach other nodes in its neighborhood (ii) topology construction: It is done based on Prims algorithm. The spanning tree constructed using this is found to be power efficient. (iii) determination of transmission power: This is done usually by measuring the received power of 'HELLO' messages. In order to locate other nodes transmission power is gradually increased. This can be applied to propagation models like free space propagation model and two ray ground model.

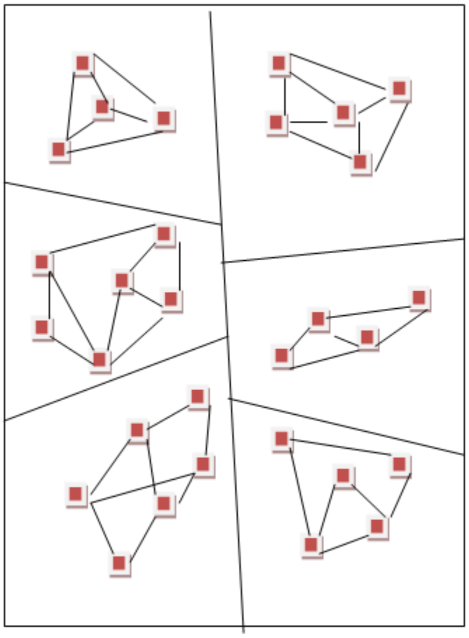

Figure:2 A Zone Based Approach

4.4 Algorithm Description

First the node determines the minimum transmission power required to reach each neighbor in N(i) in its respective zones. This information is stored in its neighbor list $N_m(i)$. Then depending on the number of nodes links are selected and topology is constructed. Topology is constructed based on the three planar structures- Gabriel Graph, Relative neighborhood graph and Local minimum spanning tree. Gabriel graph is used with nodes having lesser number of links as with greater number of links it will become less energy efficient. Relative neighborhood graph can support larger number of links when compared to Gabriel graph, but fails to maintain connectivity with large number of nodes. Hence for nodes having larger number of links local minimum spanning tree is used to maintain connectivity between the nodes and increasing network lifetime.

4.5. Algorithm for DATC

Let G(u)= (V(u),E(u)) be the input

If (signal strength is high and links are more)

{

A= { }

S ={w} (w is an arbitrary node in V)

R = V-{w}

while R is not empty do{

take an edge (i,j) such that i ε S and j ε R and (i,j) is the shortest edge

add (i,j) to A remove j from R and add j to S

}

else if(signal strength is high and links are more)

{

foreach k ε V

foreach l ε N(k)

foreach o ε N(k)

if largest $d(k,o)^2 + d(l,o)^2 < d(k,l)^2$

remove l from N(k)

remove [k ->l] from $N_m(k)$

}

else

{

foreach k ε V

foreach l ε N(k)

foreach o ε N(k)

if $d(k,o)^2 + d(l,o)^2 < d(k,l)^2$

remove l from N(k)

remove[k ->l] from $N_m(k)$

}

5. SIMULATION RESULTS

In this section simulation results to demonstrate the effectiveness of ZBTC is presented. The protocol used is DSDV and the simulation tool used is NS2. A 500*500m region is considered and 20 nodes are deployed in the region. MAC scheme used in this approach is IEEE 802.11. The metrics used in this paper are listed as follows.

5.1 Number of active links This parameter decreases as various algorithms are applied. But connectivity was found to be maintained

5.2 Number of loops smaller number of loops indicate greater packet delivery ratio.

5.3. Packet drop Smaller packet drop indicates greater delivery of packets

In the simulation study the performance of DATC is compared with the individual performance of Gabriel graph, relative neighborhood graph and local minimum spanning tree based on the above metrics at different speeds of 10m/s and 15m/s. The reason for selecting Gabriel Graph, relative neighborhood Graph and LMST for comparison is that GG has an edge length that is relatively long and preserves all minimum energy paths when the path loss exponent is 2. RNG is a sub graph of GG. LMST preserves node connectivity while preserving low transmission power.

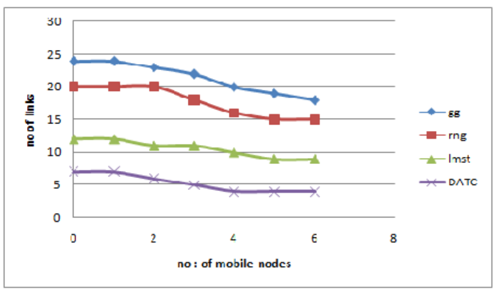

Figure: 3 Number of active links versus mobility at 10m/s

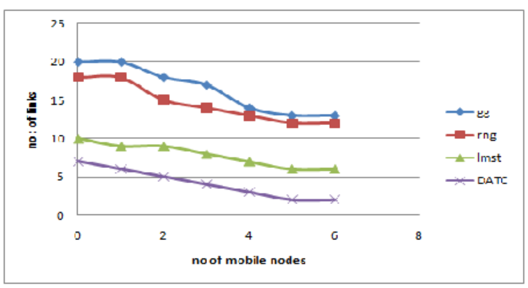

Figure: 4 Number of active links versus mobility at 15m/s

Topology of a network is defined by the set of active nodes and active links through which communication occurs. But the set of active links can be controlled. Instead of using all the links in the network, the communication can be limited to some crucial links thereby maintaining the connectivity of the network. Figure 3 and 4 shows the comparison of active links between Gabriel graph, relative neighborhood graph, local minimum spanning tree and DATC and shows that number of links is found to be less in DATC.

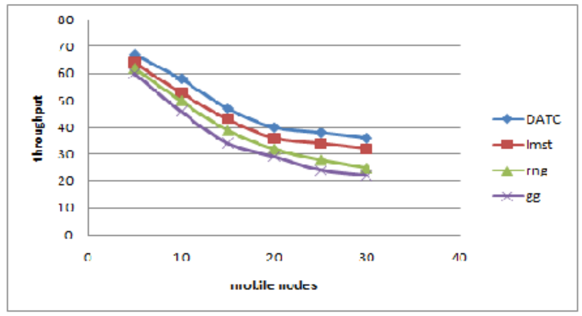

Fig.5 Throughput versus mobility at 10m/s

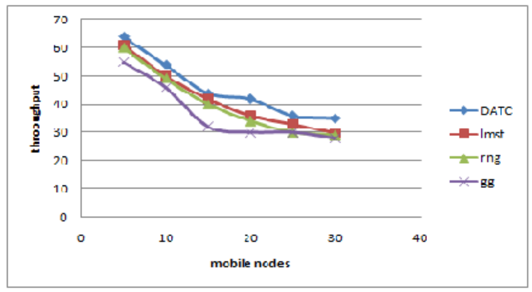

Fig.6 Throughput versus mobility at 15m/s

Throughput is the average rate of successful message delivery over a communication channel. This data may be delivered over a link, or pass through a certain network node. The throughput is usually measured in bits per second (bit/s or bps), and sometimes in data packets per second or data packets per time slot. The system throughput or aggregate throughput is the sum of the data rates that are delivered to all terminals in a network. Throughput is compared for Gabriel Graph, Relative neighbourhood graph, localized minimum spanning tree and dynamic adaptive topology control and found that throughput is more in dynamic adaptive topology control and least in Gabriel Graph

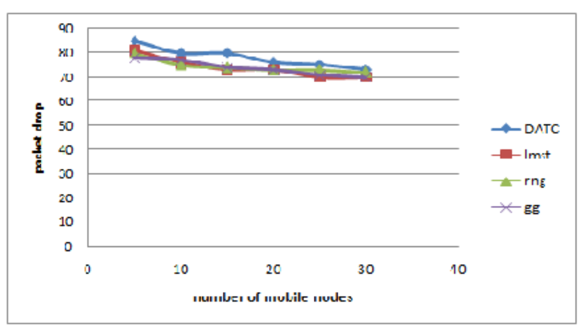

Fig.7 Packet drop versus mobility at 10m/s

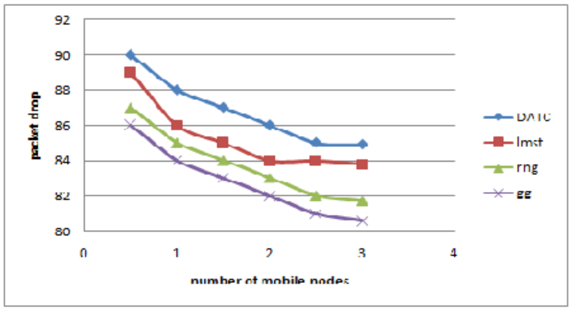

Fig.8 Packet drop versus mobility at 15m/s

Packet loss usually occurs when the packets traveling through a channel fails to reach the destination. It is one of the important errors that are encountered in digital communication. Figure 7 and 8 compares packet drop for Gabriel Graph, Relative neighborhood Graph, Local minimum spanning tree and DATC and found out that DATC has less packet drop when compared to other graphs. This is because number of loops is less in DATC when compared to Gabriel Graph, Relative neighborhood Graph, Localized minimum spanning tree. This can affect network throughput as well. If a routing loop occurs the packets will not be routed properly due to some incorrect routing information circulating in the network. One such symptom is count to infinity problem where the older routing information replaces the routing updates for an un reachable network. The metric when passed from router to router increases gradually. The routing loop will become infinite unless some limit is put on it. Routing loops are usually solved by on demand routing. Protocols like DSDV, BGP, and EIGRP have built in loop prevention.

6. CONCLUSION

In this paper a dynamic adaptive topology control has been proposed. Various routing protocols have been studied in the literature. In most of the existing works connectivity is not preserved and also the network lifetime is not guaranteed. In ad-hoc networks nodes can move anywhere at any time. As a result topology has to be controlled. The main features of this paper can be summarized as follows: (1) Network is divided into zones (2) nodes can adaptively adjust their topology (3) connectivity is preserved.

One of the main question that needs to be addressed is how to provide seamless services as the nodes proceed through the network. Hence mobility management is considered for future work considering both layer 2 routing and layer 3 routing.

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